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(54) **APPARATUS FOR VERY HIGH SPEED ADAPTIVE SPECTRUM ANALYSIS**

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  USPC 324/6.19, 76.21; 702/76; 708/3, 316; 375/229, 295; 380/15, 20
  See application file for complete search history.

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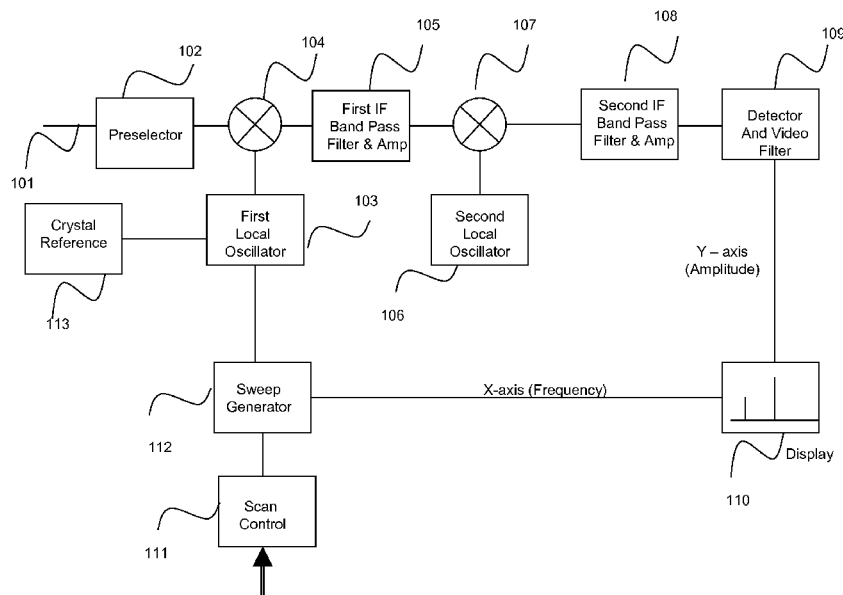|					
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(57) **ABSTRACT**

This invention describes a method by which Broadband Spectrum Analysis can be performed in the RF and Microwave frequency range with significantly higher speed, accuracy, and flexibility than existing RF and Microwave Spectrum Analyzers. This is done by eliminating the need for the filtering of the incoming signal, a process called preselection that needs to track in frequency with the scanning local oscillator in the instrument. By eliminating this requirement, this invention makes possible the identification and analysis of very broadband signals in a single sweep using an Adaptive Sweep Methodology and a Simultaneous Sweep capability that the present invention makes possible.

23 Claims, 8 Drawing Sheets

Apparatus for Very High Speed Adaptive Spectrum Analysis , Basawapatna, Attorney Docket No: BasawapatnaJan18-13

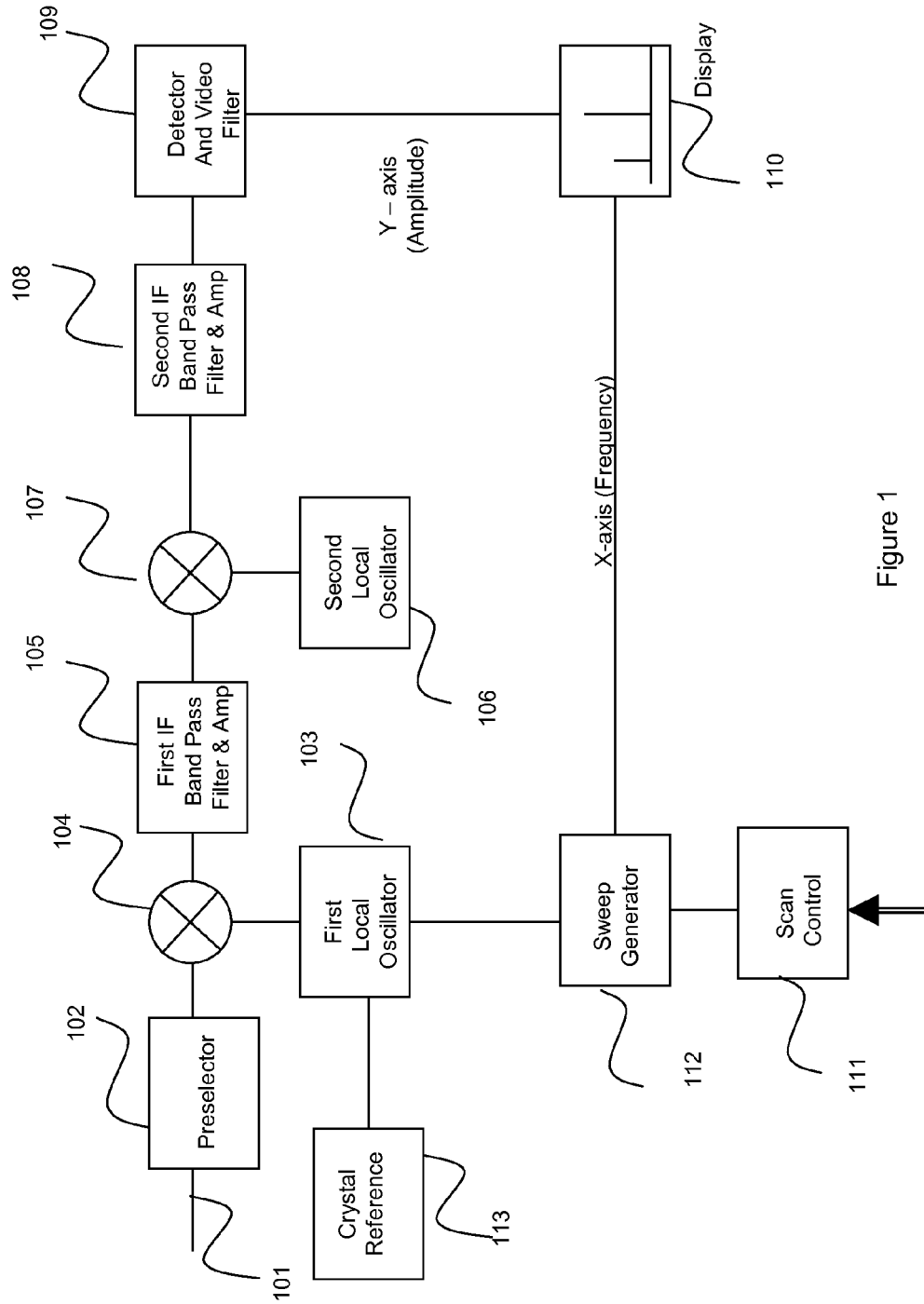Apparatus for Very High Speed Adaptive Spectrum Analysis , Basawapatna, Attorney Docket No: BasawapatnaJan18-13

Figure 1

101 Preselector
102
103 First Local Oscillator
104
105 First IF Band Pass Filter & Amp
106 Second Local Oscillator
107
108 Second IF Band Pass Filter & Amp
109 Detector And Video Filter
110 Display
111 Scan Control
112 Sweep Generator
113 Crystal Reference

Y – axis (Amplitude)

X-axis (Frequency)

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Coil with Current I,
Resistance R, and Inductance L

205

To Coil Driver
V = RI + Ldi/dt

201

Filtered
Output

YIG Sphere
202

204

Loop ground
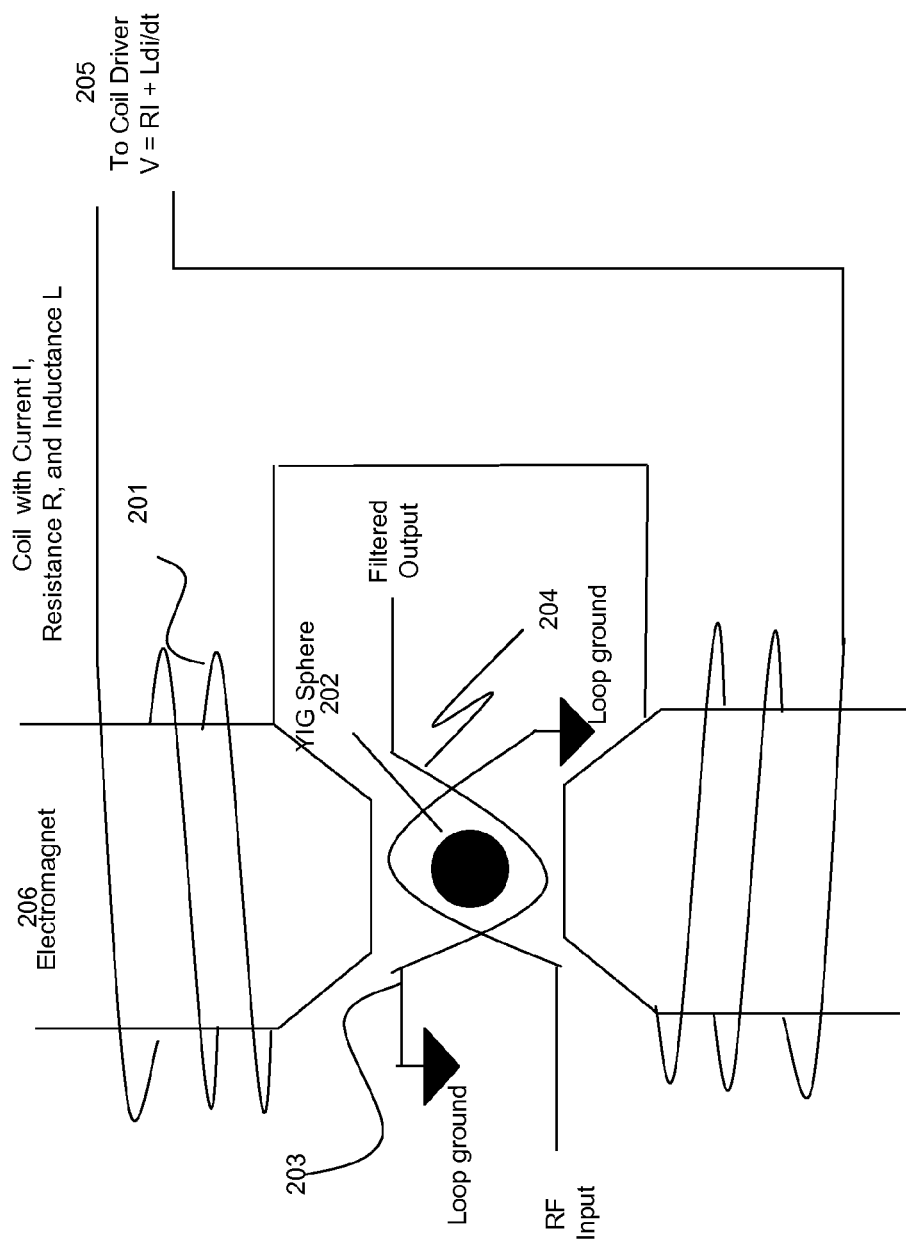
206
Electromagnet

203

Loop ground

RF
Input

Figure 2

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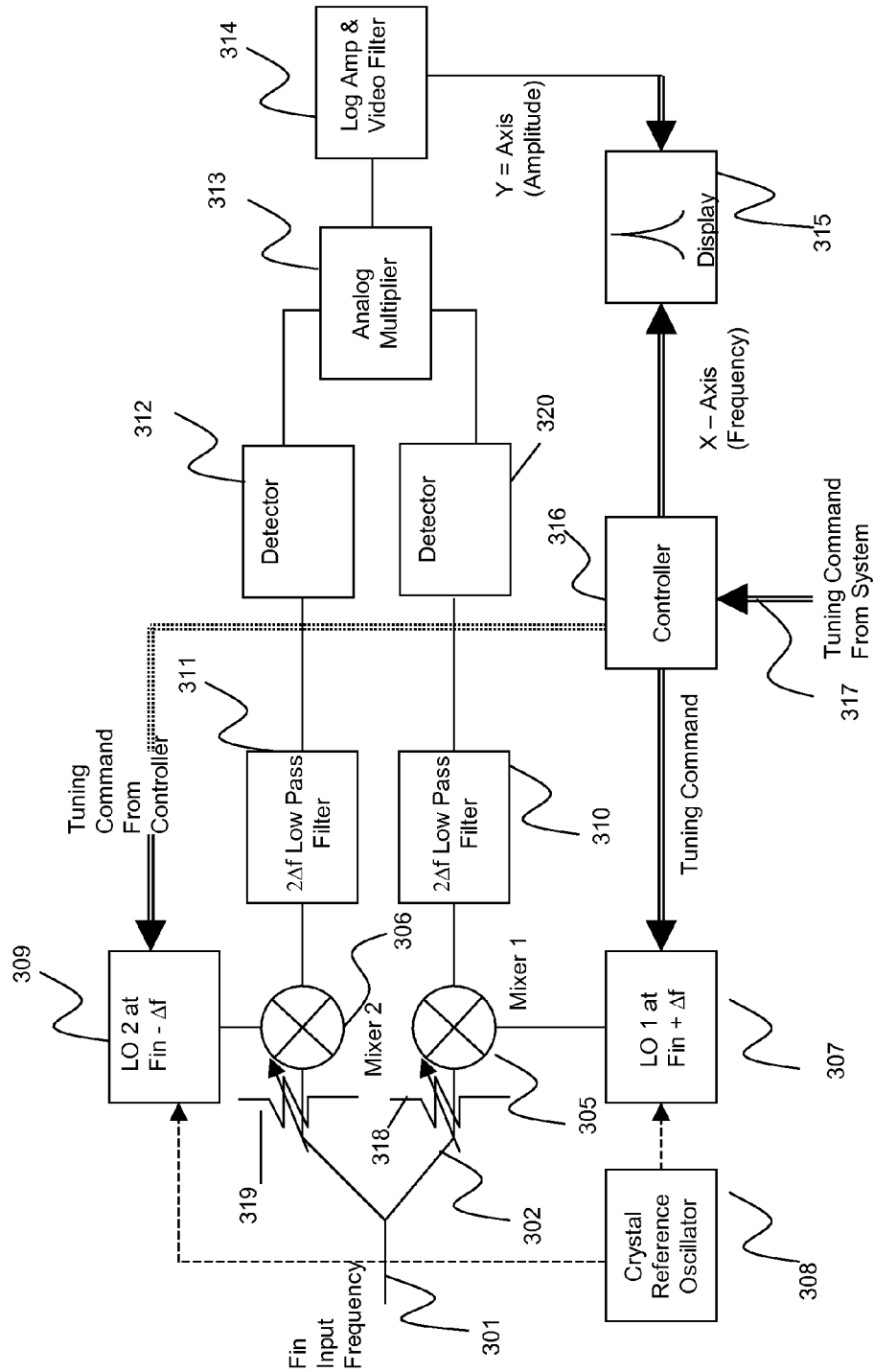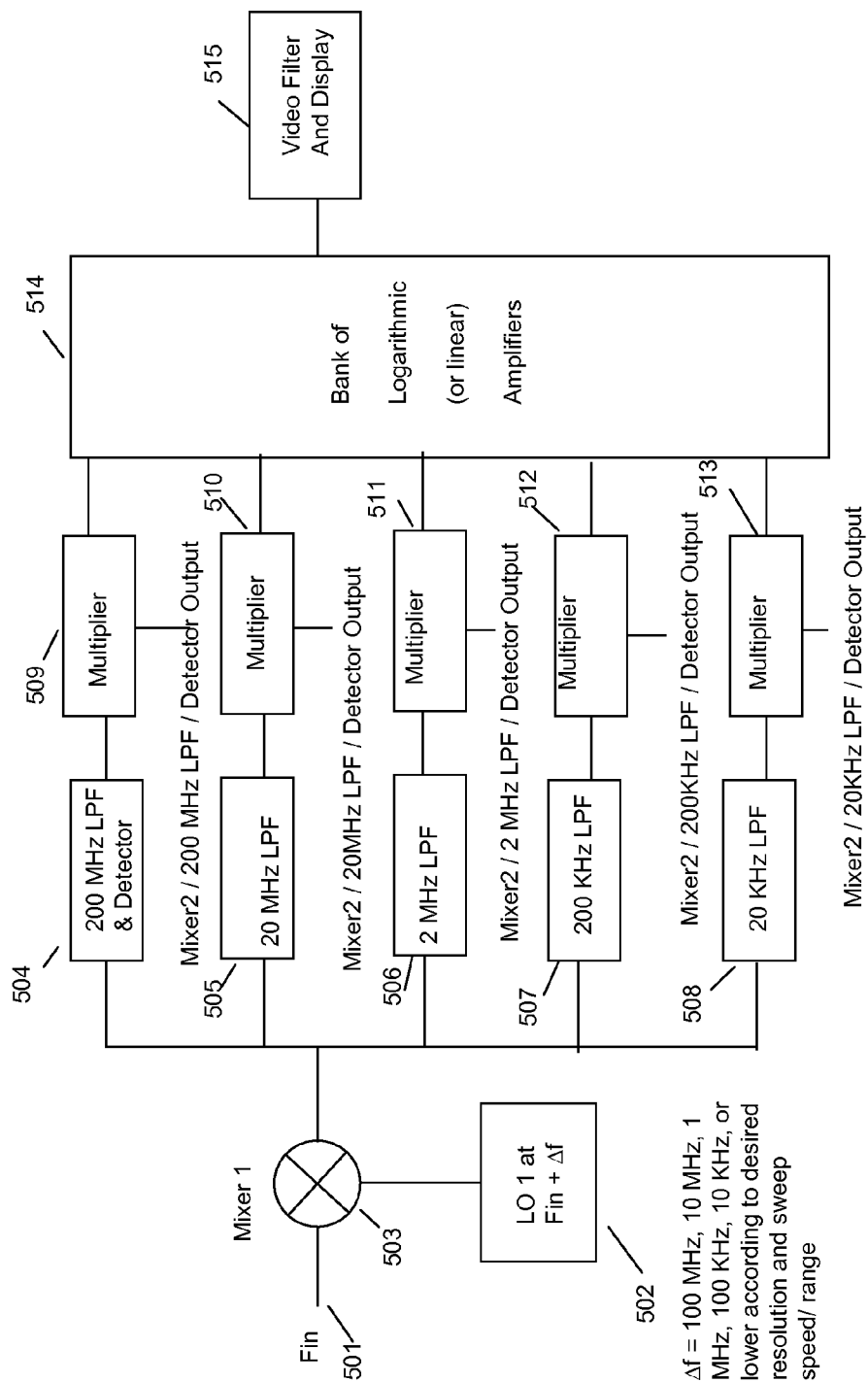

Figure 3

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Effect of a signal at frequency 5000 MHz, with Flo increasing in steps from 4960 to 5070 MHz with Δf = 10 MHz
Input Noise is output when either 2 Δf LPF output is zero
Multiplier output produces signal proportional to input from Flo = 4990 MHz to Flo 5010 MHz
All frequencies in table are in MHz

Flo	LO 1 at Flo + Δf	IF @ Mixer1	2 Δf LPF Output Frequency@ Mixer 1	LO 2 at Flo - Δf	IF @ Mixer2	2 Δf LPF Output Frequency @ Mixer 2	Multiplier Output
4950	4960	40	-	4940	60	-	Input Noise
4960	4970	30	-	4950	50	-	Input Noise
4970	4980	20	20	4960	40	-	Input Noise
4980	4990	10	10	4970	30	-	Input Noise
4990	5000	DC	DC	4980	20	20	Input Signal
5000	5010	10	10	4990	10	10	Input Signal
5010	5020	20	20	5000	DC	DC	Input Signal
5020	5030	30	-	5010	10	10	Input Noise
5030	5040	40	-	5020	20	20	Input Noise
5040	5050	50	-	5030	30	-	Input Noise
5050	5060	60	-	5040	40	-	Input Noise
5060	5070	70	-	5050	50	-	Input Noise

Figure 4

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Fin
501

Mixer 1

503

LO 1 at
Fin + Δf

502

Δf = 100 MHz, 10 MHz, 1 MHz, 100 KHz, 10 KHz, or lower according to desired resolution and sweep speed/ range

504

200 MHz LPF
& Detector

Multiplier
509

Mixer2 / 200 MHz LPF / Detector Output
510

505

20 MHz LPF

Multiplier

Mixer2 / 20MHz LPF / Detector Output
511

506

2 MHz LPF

Multiplier

Mixer2 / 2 MHz LPF / Detector Output
512

507

200 KHz LPF

Multiplier

Mixer2 / 200KHz LPF / Detector Output
513

508

20 KHz LPF

Multiplier

Mixer2 / 20KHz LPF / Detector Output

514

Bank of

Logarithmic

(or linear)

Amplifiers

515

Video Filter
And Display

Figure 5

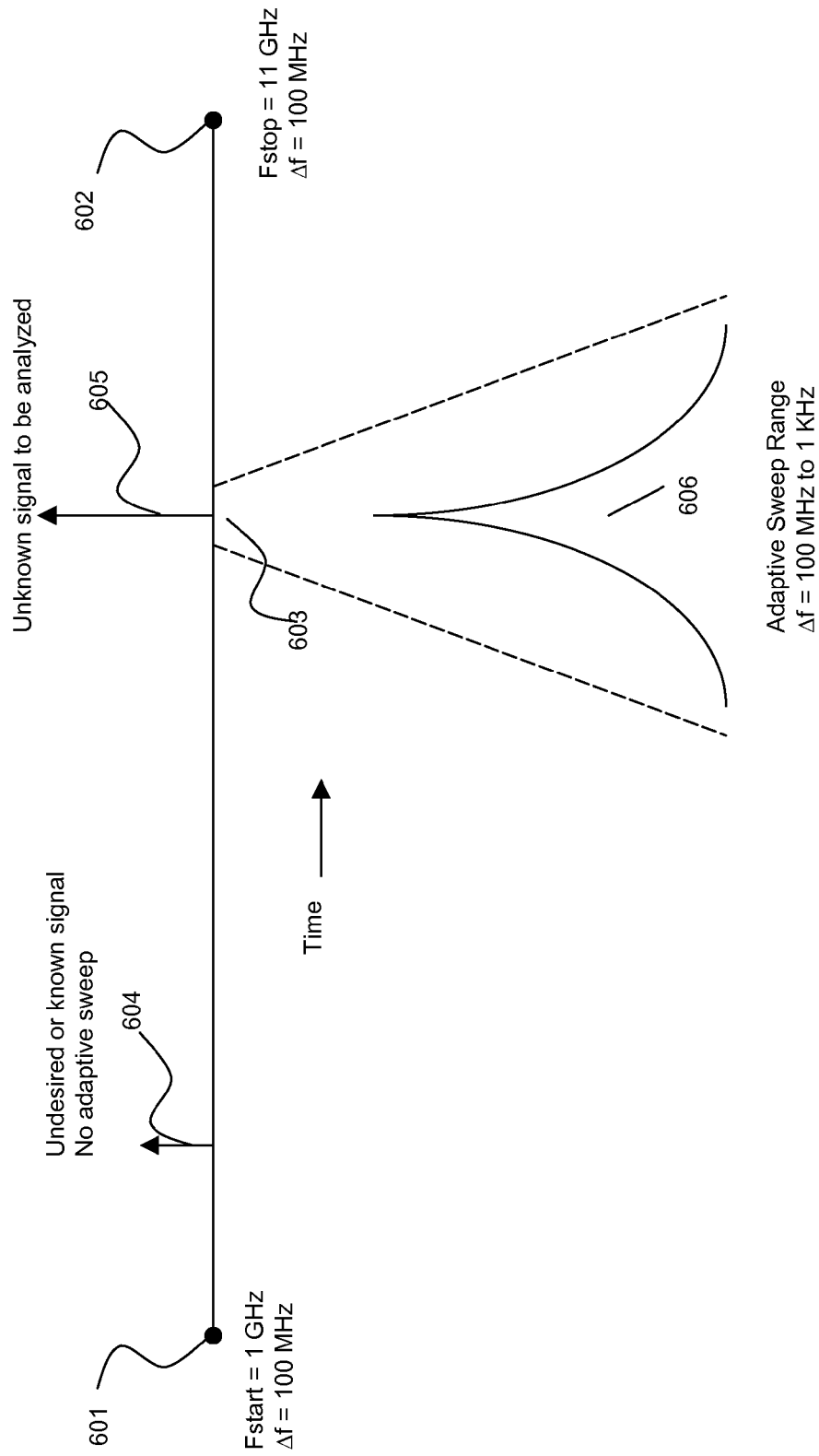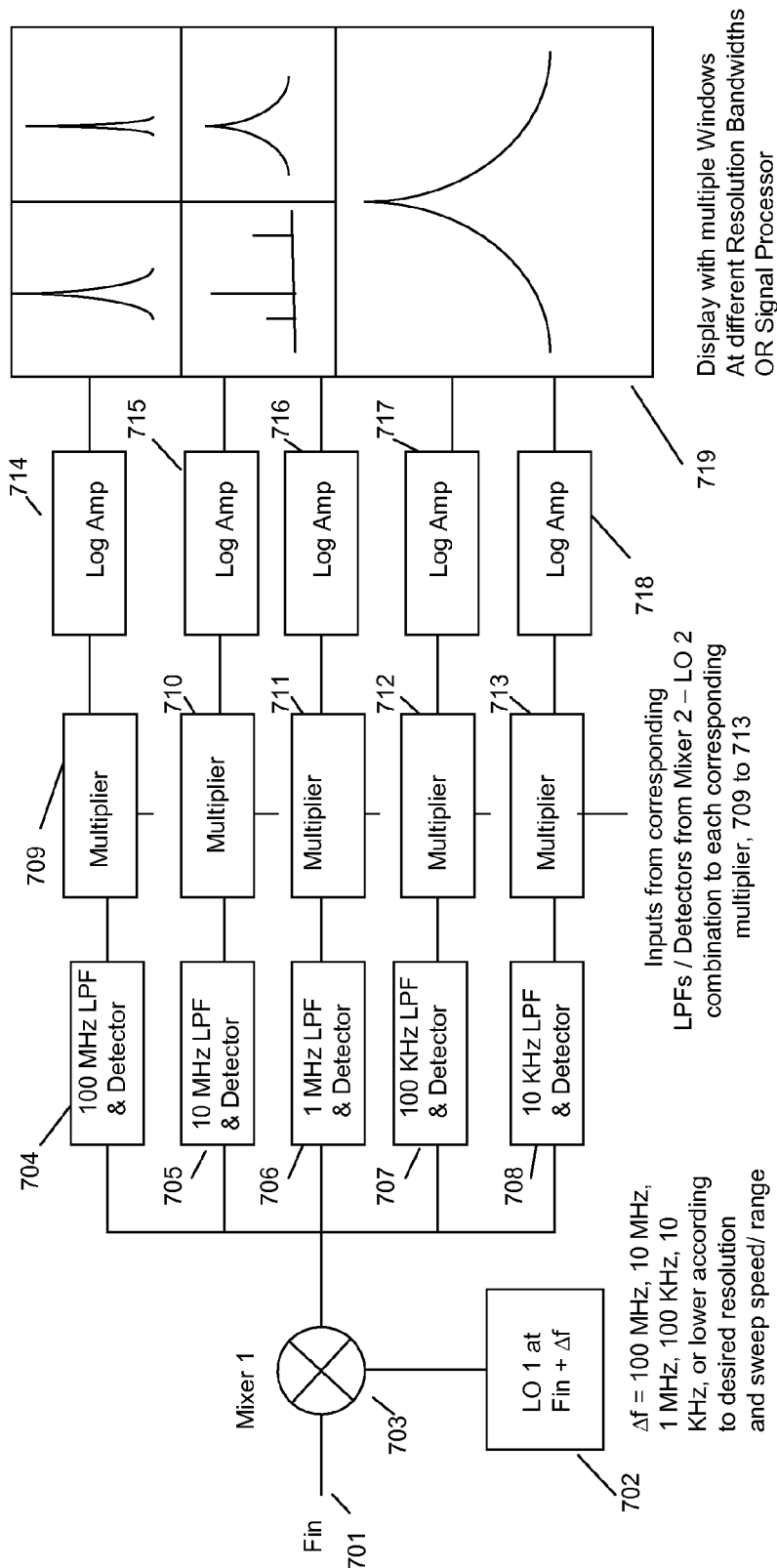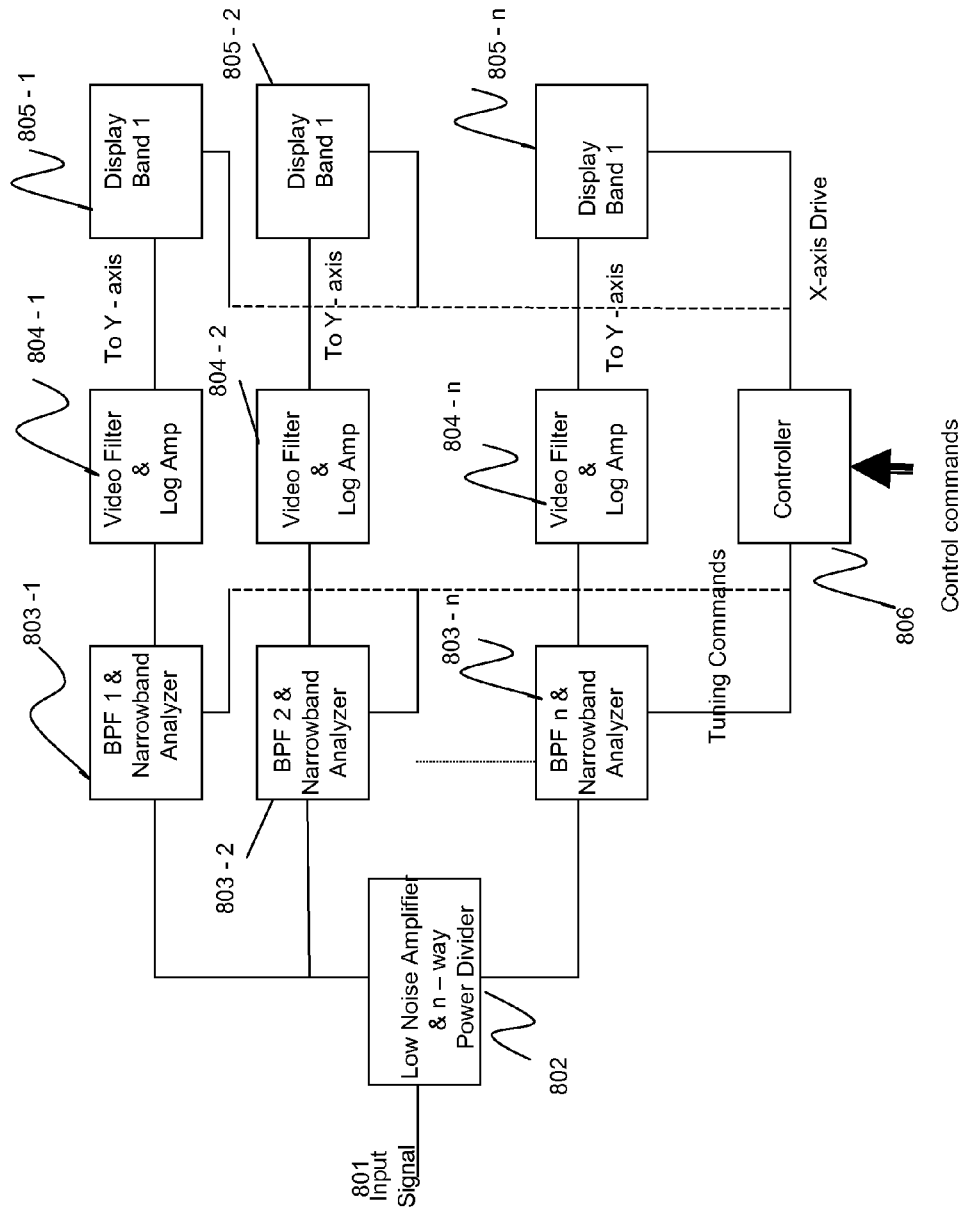Apparatus for Very High Speed Adaptive Spectrum Analysis , Basawapatna, Attorney Docket No: BasawapatnaJan18-13

Unknown signal to be analyzed

602

Fstop = 11 GHz
Δf = 100 MHz

605

603

606

Adaptive Sweep Range
Δf = 100 MHz to 1 KHz

Undesired or known signal
No adaptive sweep

604

Time

601

Fstart = 1 GHz
Δf = 100 MHz

Figure 6

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Figure 7

Fin 701

Mixer 1

703

LO 1 at Fin + Δf

702

Δf = 100 MHz, 10 MHz, 1 MHz, 100 KHz, 10 KHz, or lower according to desired resolution and sweep speed/ range

704 — 100 MHz LPF & Detector

705 — 10 MHz LPF & Detector

706 — 1 MHz LPF & Detector

707 — 100 KHz LPF & Detector

708 — 10 KHz LPF & Detector

709 Multiplier

710 Multiplier

711 Multiplier

712 Multiplier

713 Multiplier

Inputs from corresponding LPFs / Detectors from Mixer 2 – LO 2 combination to each corresponding multiplier, 709 to 713

714 Log Amp

715 Log Amp

716 Log Amp

717 Log Amp

718 Log Amp

Display with multiple Windows At different Resolution Bandwidths OR Signal Processor

719

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Figure 8

801 Input Signal

802 Low Noise Amplifier & n – way Power Divider

803 - 1 BPF 1 & Narrowband Analyzer
803 - 2 BPF 2 & Narrowband Analyzer
803 - n BPF n & Narrowband Analyzer

804 - 1 Video Filter & Log Amp
804 - 2 Video Filter & Log Amp
804 - n Video Filter & Log Amp

To Y - axis

805 - 1 Display Band 1
805 - 2 Display Band 1
805 - n Display Band 1

Tuning Commands

806 Controller

Control commands

X-axis Drive

APPARATUS FOR VERY HIGH SPEED ADAPTIVE SPECTRUM ANALYSIS

FIELD OF THE INVENTION

This invention pertains to a method to create the ability to analyze RF and microwave signals via a new form of spectrum analyzer.

DEFINITION OF TERMS

Local Oscillator (LO): When a signal frequency is desired to be translated to another frequency a Local Oscillator is used in conjunction with a mixer to create the Intermediate Frequency (IF).

Mixer: When two frequencies, F1 and F2 are input to two ports of a mixer, it typically generates $\pm m \cdot F1 \pm n \cdot F2$, frequencies, where m and n are integers.

Intermediate Frequency (IF): All the resultants of the mixing process in the above paragraph are called Ifs. In particular, frequencies generated with m=n=1 are most often used in Fundamental Mixing.

IF Bandwidth: The bandwidth of the filter, which is typically a band-pass filter that follows the mixer and selects only the desired IF.

Video Detector: A device that creates a DC voltage proportional to the amplitude of the RF or IF signal applied to it.

Log Amp: Logarithmic Amplifier. Usually follows a detector and creates an output which is logarithmically proportional to the output so that the output can be displayed in decibels (dB).

YIG: Yttrium Iron Garnet. It has the property that it exhibits ferromagnetic resonance that is directly proportionate to the applied DC magnetic field, and this resonance can be coupled to by external circuits to build oscillators and band-pass or band-reject filters.

Sweep: Also called frequency sweep. It is the tuning of an oscillator or in some cases a filter from some start frequency to some stop frequency. It is possible to sweep in an Analog fashion where the frequency changes continuously with time, or in digital fashion, where the frequency steps discretely with time.

Reference Oscillator: An oscillator usually based upon an ideal resonator such as a Crystal Resonator with the property that its output waveform is very stable and has very low frequency drift and very low phase noise sidebands.

Resolution Bandwidth: This is the effective bandwidth within which the signal power is measured. It is used to measure the average power of a signal within a particular bandwidth. The narrower the resolution bandwidth, the more accurately are the sidebands of a carrier measured. However, narrower resolution bandwidths traditionally also mean longer measurement times, often with multiple sweeps.

BACKGROUND OF THE INVENTION

RF and Microwave Spectrum Analyzers are and have long been an important instrument family, used in a variety of applications including Laboratory analysis of signals and modulation spectra, Telecommunications signals, Satellite Communications, Electronic Warfare and other Defense applications. Recently, due to the increased use in WiFi applications such as 3G, 4G, and LTE architectures, it has become very important to have handheld spectrum analyzers that are light weight, have long battery life, and still have a high

degree of accuracy. In addition the ability to quickly identify and analyze received signals has become very critical in many defense applications.

Most spectrum analyzers are built using a heterodyne type design. This is shown in block diagram form in FIG. 1. The incoming signal 101, whose frequency and other spectral characteristics are unknown, is mixed or frequency converted in a series of mixers 104 and 107 in this figure (or more or fewer mixers as desired by the designer of the analyzer) with a series of local oscillators 103 and 106, the first of which, 103 in FIG. 1, typically, is a swept signal source that is capable of being frequency synthesized to a desired level of frequency accuracy and stability. The mixer 104 output of this First Local Oscillator also called First LO, is filtered through a fixed bandwidth bandpass filter 105 to produce a First Intermediate Frequency, or First IF. Assuming that the purity of the First LO is much better than that of the incoming signal, any input to the signal analyzer will produce a signal with the same spectral characteristics as the input signal at the First IF at frequencies given by

$$Fif = \text{Absolute value of}(\pm m \cdot Flo \pm n \cdot Fsig)$$

Where Fsig is the frequency being scanned for the existence of a signal, and m and n are integers. Typically all IF frequencies other than the desired one are eliminated by means of the First IF filter 105. In many analyzers m=1, but m can be 1,2, or a higher number depending upon the harmonic of the LO that the signal will mix with to produce Fif. Both $m \cdot Flo + Fsig$ and $m \cdot Flo - Fsig$ will create identical outputs at the input to the First IF. However, only one will be equal to Fif, and this signal will pass to the second W. After the First IF, a series of mixers, in this Figure, 107 is utilized in order to more accurately filter the First IF and to make it possible to detect, measure 109 and display 110 the resultant translated form of the input signal with the maximum amount of fidelity to the actual input signal as possible. This set of filter bandwidths is often called the Resolution Bandwidth of the analyzer, and it can be varied from front panel or remote controls. Unfortunately, the creation and existence of multiple harmonics of the signal and LO frequency within the mixer implies that there is the mathematical possibility that for some other values of n and m, $n \cdot Fsig$ mixing with $m \cdot Flo$ creates a signal at Fif. In this case, this signal will pass through as if it were a legitimate signal. This is called an image response. This is not acceptable as it can produce a spurious signal display at a frequency where there is no actual signal present at the input. In order to eliminate this, the input signal is passed through a tunable filter 102 that tracks the first LO frequency with an offset equal to the First IF frequency such that only the desired signal can cause the desired IF. This is called a Preselector, and in broadband analyzers the function is often realized by a tunable bandpass filter called a YIG tuned Filter (YTF). The LO is often a Yig Tuned Oscillator (YTO). If the YTF is integrated with the mixer, as is often done, such a component is called a Yig Tune Mixer or YTX.

There are many advantages to this traditional approach, the most important of which is that, until this present invention there always was needed a preselector, and there was no easy way other than a YIG device to achieve a broadband tunable Preselector Filter that tracked in frequency with a Local Oscillator. YIGs depend upon the resonance of Yttrium Iron Garnet spheres in the presence of a magnetic field. This resonance is almost linear with the applied magnetic field, so that if the magnetic field is realized by means of an electromagnet, the resonator can be frequency tuned over a wide frequency range in a linear relation to its drive voltage or current. A typical YIG structure is shown in FIG. 2, where the coil 201

tunes the sphere **202** via the electromagnet **206**, creating a tuned resonance in coupling RF loops **203** and **204** (in this example a filter) that is the basis of the tuning of the filter in the YTF. When an oscillator is needed, only one coupling loop, for example 203 is used as a resonator for the local oscillator, YTO. In a YTF, at the resonance frequency if the loops are orthogonal, the RF energy is coupled into the sphere and transferred to the output loop. At all other frequencies there is no energy transfer except for leakage. The advantage of YIG resonance is that it has a high Quality Factor, called Q, which is a measure of purity of resonance, which allows for very good signal selectivity. The disadvantages unfortunately are many. The electromagnets have significant hysteresis which needs to be corrected. Their linearity is not perfect. They suffer from significant thermal drift. They require very high voltages to allow the magnets to overcome the tuning coil IR (current, 1 times Resistance R) voltage drops, and the L·(di/dt) drop, where L is the coil inductance and di/dt is the rate of change of current with time. This severely limits the speed with which the YIG devices can be tuned to different frequencies. In a spectrum analyzer, where the LO and preselector filter need to exactly track each other within the first IF bandwidth, these drifts impose significant other constraints. Another very difficult constraint is that while the YTO can indeed be phase locked or synthesized to any accuracy its crystal reference, **113**, in FIG. **1**, provides, the YTF, being essentially open loop, cannot have such accuracy. As a result, in YIG tuned spectrum analyzers, except for the start of a sweep, the first LO is never phase locked or accurate as a locked oscillator. The sweeps are essentially analog sweeps and the measurements at any frequency are subject to this analog inaccuracy. As a result, often, to narrow down on a signal the instruments need to follow a sequence of Peak Search, selecting the maximum value of the signal display—Centering the Frequency Band around the Peak—then reducing the span has to be done many times. Thus for each reduction of resolution bandwidth a minimum of 3 sweep are needed. To narrow down a signal from a 10 GHz span to a 100 KHz span, often 30 or more sweeps, each taking up 50 to 400 milliseconds are needed so that any measurement that requires this accuracy may need 5 to 10 seconds.

Other methods have been proposed and tried to solve these problems. It is possible for example, and has been proposed, to build the preselector out of a bank of switched bandpass filters. The problem with this solution is that if one wanted to build a broadband analyzer covering many decades of frequency range, many microwave filters would be required, along with banks of microwave switches. This is a very expensive and almost impractical solution. As a result this is not a method that is used except in specific narrow bandwidth instruments for very specialized applications. Another method that is used in many fixed or narrow frequency range receivers is called the Zero-IF receiver. Here, the mixer output is filtered with a very low frequency low pass filter, and when the LO frequency is equal to the input frequency there is a DC output voltage. There are no extra stages of IF. The problem with this method is that the IF is really a DC or close to DC value, which requires to sweep the signal very slowly, and is not usable even in moderate bandwidth receivers. Zero IF receivers are used, and are very effective in fixed frequency receivers, for example in testing known communication channels. They are very impractical in broadband receivers.

Another problem with these traditional approaches is that, to identify the existence of signals in the frequency range of interest and then to analyze the modulation, phase noise, or other characteristics of the spectra, multiple sweeps are needed. Since, due to YIG tuning speed limitations, each

sweep is typically several hundred milliseconds in duration, any measurement that takes multiple sweeps will take many seconds to complete. In an agile signal environment for example in Electronic Warfare this is not be acceptable.

The present invention addresses these issues. It uses a completely different architecture to eliminate the need for preselection, so that accurate signal analysis can occur in microseconds, 100 to 1000 times faster than existing methods.

SUMMARY OF THE INVENTION

This invention recognizes that preselection is a filter-tuning process, and such a process over multi octave bandwidths slows down the speed of measurement, and is dependent on the preselector filter characteristics. A new, faster moving image spurious elimination paradigm is needed. This invention eliminates the need for preselection in spectrum analyzers.

This invention accomplishes the objective by a non-intuitive process that results in creating an IF frequency output if only if the input is at the correct frequency.

This is done, as will be explained in the sections below, by stagger tuning the input with a narrow frequency differential in two sections that results in an output only when a real signal exists at the scanned frequency and the output can only be created by a non-image frequency. We demonstrate that physically realizable higher order harmonics of the expected signal frequency cannot produce a desired IF frequency in both paths.

The system requires two digital or digital/analog tuned Local Oscillators that are programmable a fixed frequency apart. Both local oscillators are synthesized, and are capable of continuous multi-octave frequency tuning.

At the same time, this method allows the spectrum analyzer designed by this new method to change the sweep characteristics for quicker verification of signal dynamically in mid sweep. This process which we call Adaptive Sweep is a new functionality created by this invention. In addition, this method allows a user to simultaneously analyze the incoming signal with multiple resolution bandwidths. This process, called Simultaneous Processing, is also a new functionality that the present invention makes possible. As we will show this allows for very quick identification of signals, and to allow a method to narrow down on signals quickly, by reducing the resolution bandwidth in a narrow range and slowing down the sweep selectively, during the sweep, rather than waiting for a next sweep as the old method would require the system to do.

This is demonstrated in the detailed description of the invention that follows. Our invention provides almost all the advantages of the traditional preselected spectrum analyzer with faster speed, lower cost, and smaller size so truly exceptional performance handheld solutions can be created for signal analysis.

BRIEF DESCRIPTION OF THE DRAWINGS

The exemplary embodiments are best described by referring to the drawings attached. It should be emphasized that these drawings are for the purpose of explanation only. Many of the components shown in these exemplary drawings can be replaced by other components or combination of components achieving the same purpose.

FIG. **1**. shows a traditional Spectrum Analyzer realization in block diagram form.

FIG. **2** shows a typical YIG preselected Spectrum Analyzer in block diagram form.

FIG. **3** shows a possible basic concept of the High Speed Spectrum Analyzer this invention represents.

FIG. **4** shows the effect of sweeping through a signal range in a table form to make the concept clearer.

FIG. **5** shows the concept of an Adaptive Spectrum Analysis using one half of the analyzer architecture.

FIG. **6** shows the ability to perform multiple Resolution bandwidth measurements simultaneously.

FIG. **7** shows the how the system can be used for Simultaneous Signal Analysis.

FIG. **8** shows the realization of a device similar to the Instantaneous Frequency Measurement Devices that is another result of the present invention.

DETAILED DESCRIPTION OF THE PROBLEM TO BE SOLVED, AND PREFERRED EMBODIMENTS

The invention concepts are described in this section using the drawings referred to. They do not represent all possible embodiments, but are used primarily for illustrative purposes.

The proposed instrument block diagram is shown in simplified form in FIG. **3**. The input signal **301** at frequency Fin is split into two equal signals at the splitter **302**. One half of the signal is input to Mixer1, **305** and the other half to Mixer 2, **306**. The local oscillator **307** for Mixer 1 is at a frequency Flo+Δf, and the local oscillator **309** for Mixer 2 is at frequency Flo−Δf. The value of Δf is kept constant and Flo is varied linearly with time from start frequency to some stop frequency, which define the region of interest for incoming signals. Both the local oscillators at Flo+Δf and at Flo−Δf are frequency synthesized at every point in the sweep and are controlled by the same crystal reference **308**, so that they are exactly 2Δf apart in frequency. The offset Δf can be a very small offset, for example 10 KHz, or very large, for example 10 MHz or even higher. Of course, Δf can be chosen to be any number depending upon the spectrum analyzer signal parameters desired, as will be discussed later. The Mixer 1 and Mixer 2 outputs are at frequencies given by

$$Fmix1 = \pm m \cdot Fin \pm n \cdot (Flo + \Delta f) \qquad (1)$$

and

$$Fmix2 = \pm m \cdot Fin \pm n \cdot (Flo - \Delta f) \qquad (2)$$

where m and n are integers. Ignoring all but fundamental mixing products for the time being for the purpose of demonstrating the principles of the invention, m and n are both set at 1. The outputs of mixers 1 and 2, Fmix1 and Fmix2 are filtered by low pass filters **310** and **311** that cut off, for this example, at 2Δf. There are three possibilities depending upon Fin, Flo and Δf:

Fin>Flo+Δf, so that Fmix1 >Δf,   Case 1 or,

Fin<Flo−Δf, so that Fmix2 >Δf   Case 2 or,

Flo+Δf>Fin>Flo−Δf so that Fmix1 <Δf and Fmix2<Δf   Case 3

In the first two cases each of the two mixer products Fmix1 and Fmix2 will be filtered out by its low pass filter leaving no input to Detector **312** or Detector **320**, so that Analog Multiplier **313** will have no output other than frequency translated incoming noise power. In the third case both mixers will have an output within the 2Δf low pass filter range. In the special case where Fin=Flo+Δf, or Fin−Flo−Δf we have a DC output, which is usually called a zero beat. In general, the Analog

multiplier **313** will have an output in proportion to the input signal amplitude within the 2Δf frequency range.

This is demonstrated in table form in FIG. **4**, where the input signal is at 5000 MHz and the two local oscillators Flo+Δf and Flo−Δf are swept as shown in 10 MHz steps. The outputs of Low Pass Filters **310** and **311** can be seen to both have non zero values only between Flo of 4990 and 5010 MHz, which is centered around the signal frequency of interest, 5000 MHz. Thus the detectors **312** and **320** will have non-zero outputs and the Analog Multiplier **312** has an output only within this frequency range. The detectors employed are typically square law detectors, so that the output voltage of the detector is proportional to the input power. This output is amplified logarithmically in the logarithmic amplifier— video filter combination **314** to convert the signal so it can be shown on a decibel scale, and to average out the effects of the low frequency noise, and sent to the Y-axis of the display **315**. Of course, the Logarithmic amplifier in this description is for discussion purposes only. It can also be replaced with a linear amplifier if a linear power display is desired. The X-axis of the display **315** is derived from the Tuning Command **317** via controller **316**. Controller **316** also sends frequency synthesis commands to LO1 **307** and LO2 **309**.

It should be pointed out that this example, while realistic, is mainly meant to illustrate the functionality of the system. As will be shown shortly, by the judicious choice of M, and use of multiple filters, detectors and multipliers, the system allows for the resolution bandwidth of the analyzer to be varied so that the system sensitivity is increased or decreased on the fly as desired to enable accurate measurements on incoming signals. It should also be pointed out that at any input frequency Fin that the spectrum analyzer is tuned to, there is a certain amount of noise power input due to ambient (also called kTB) noise and other noise sources inherent to active and passive devices, so that, in the absence of any signal at 5000 MHz in the example of FIG. **4**, there will still exist frequency converted input noise. Also, if the mixer LPF bandwidth is only 20 KHz, for example, then there will only be a response between Flo frequencies of 4999.99 MHz and 5000.01 MHz. The selection of the value of Δf and the low pass filter bandwidth effectively control the resolution bandwidth of the instrument, in other words how accurately the incoming signal frequency can be resolved and its amplitude can be determined. In addition, outputs of the signal splitter **302** can be equalized by optionally installing programmable attenuators **318** and **319** at the splitter outputs. Knowing the LO frequency, with a EEPROM resident table in controller **316**, for example, attenuators **318** and **319** can be controlled so that the inputs to mixer 1 and mixer 2 are equal in amplitude to each other at any input frequency being scanned. Alternatively, a closed loop method can be employed that samples the split signals and attenuates one path or the other in such a fashion that the signals are equal in amplitude at the input of each mixer.

Referring to the table in FIG. **4** again, consider what happens if the LO frequency separation Δf is kept at 10 MHz and the mixer output is put through a lowpass filter of bandwidth Δfl=20 KHz. In this case at the range of frequencies Fin such that the Absolute value of (Fin−Flo)<Δfl, there will be a detected signal proportional to the input signal. What this implies is that by keeping the LO frequency separation Δf large, for example 100 MHz, and passing the mixer output through different low pass filters of different bandwidths Δfl, multiple resolution measurements can be simultaneously made within a single sweep. This powerful advantage is described in greater detail later in this document. Of course, in order to take full advantage of this power, the sweep itself

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would need to be an Adaptive Sweep, that is a sweep that slows down and uses smaller LO frequency step sizes when Δfl is reduced, and speeded up with commensurately larger LO step, sizes when Δfl is increased. In effect, the Adaptive Spectrum Analyzer speeds through regions where there are no signals of interest, and slows down to a speed, commensurate with Δfl, when a signal of interest is to be viewed in greater detail or analyzed.

We now show how the method eliminates the need for preselection. Consider one leg of the input section as shown in equation (1) above. The question is, if m=n=1 satisfies the equation

$$\text{Abs}[Fin-Flo]<\Delta f,$$

where the symbol ≤ implies "less than or equal to", and where Abs[x] implies the absolute value of the quantity x within the square brackets, then can any other integer values of m>1 and n>1 exist such that

$$\text{Abs}[m \cdot Fin - n \cdot Flo] \leq \Delta f.$$

Substituting Flo=Fin+Δf, the above equation can be written as

$$\text{Abs}[(m-n)Fin-n\Delta f] \leq \Delta f$$

Which can be simplified by dividing both sides by n·Δf to give

$$\text{Abs}[(m/n-1)(Fin/\Delta f)-1] \leq 1/n$$

At microwave frequencies where Fin is of the order of 1 or more GHz and with Δf of the order of 10 MHz or less, Fin/$\Delta f \gg 1$. Three cases arise from this inequality, which are m=n, or m>n, or m<n. If m=n, then the above equation reduces to

$$1/n > 1, \text{ which is possible only if } n=1.$$

If m>n, then since Fin/$\Delta f \gg 1$, the relation can be shown to reduce to

$$(Fin/\Delta f) \cdot (m/n) \leq (Fin/\Delta f)+1+1/n$$

If, for example Fin=1 GHz and Δf=10 MHz, Fin/Δf=100, and the equation reduces to

$$100m/n \leq 101+1/n, \text{ or } m < 101n/100+1/n$$

In the limit, as n tends to very high integer values this says m<n. at the lowest possible value of n, which is n=1, m<1.01+1, i.e. m=1 which we already discussed. Given the starting assumption for this case that m>n this leads to a contradiction since m cannot be greater and smaller than n at the same time. That is, if Fin$\gg\Delta f$ no solution such that m>n exists.

Taking now the third case, where m<n, the equation can be shown to reduce to

$$\text{Abs}[1-(1-m/n)(Fin/\Delta f)] \geq 1/n.$$

For the smallest possible value of m, m=1, this reduces to

$$1-1/n \geq (1-1/n)(Fin/\Delta f)$$

which is a mathematical impossibility if Fin>Δf.
We have thus proved that under any practical circumstance, no image frequency can exist. In actuality, since equation (2) above would also need be simultaneously satisfied to have an output at detector 313, this clearly shows that there is no preselection needed.

The power of this technique is that, in an environment where there are a number of discrete frequency ranges with possible signals, such as in a multiple radar environment, it is possible to sweep very wide frequency ranges with a large Δf at very high sweep rates, and when a signal of interest is spotted, to immediately decrease Δf in order to more accurately measure the frequency and identify its sidebands and

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modulation characteristics. Since there is no need for preselection, the spectrum analyzer we propose here can scan the incoming signal environment at very wide apertures and quickly identify and home-in on any desired signal without having to resort to multiple sweeps.

To summarize, if a signal at frequency Fsig=Fin is input to the our spectrum analyzer such that the absolute value of (Fsig–Flo)≤Δf the output of filter 310, 311 and multiplier 312 will be exactly proportional to the input signal level. At frequencies where the absolute value of (Fsig–Flo)>Δf, there is no output other than that proportional to the input noise at frequency Fsig.

We have demonstrated that our technique eliminates the need for preselection, and therefore for a Preselector Filter and a Local Oscillator to track each other in frequency over wide frequency ranges as the traditional Spectrum Analyzers do. This eliminates the need for slower magnetically tuned YIG devices, which are replaced with 100 or more times faster varactor tuned and frequency synthesized all solid state Local Oscillators or Direct Digital Synthesized (DDS) oscillators. Further, the Local Oscillators of this proposed system are synthesized and accurate at every measurement point, unlike the YIG devices, which are not phase locked and therefore truly accurate only at the starting frequency of each sweep.

A resultant powerful feature made possible by the invention is demonstrated in FIGS. 5 and 6. FIG. 5 shows another possible realization in greater detail. In this figure, in order to make the explanation simpler, we show only one half of the input signal path where Fin, 501 is the signal into one of the two mixers after the input splitter. Fin is mixed with Flo1 which in this half of the block diagram is Fin+Δf. At the initial start of a measurement for an unknown signal, if the frequency range of the desired signal is unknown, we would need a wide sweep, and a wide Δf, which in this case may for example, be 100 MHz. A 100 MHz Δf and 100 MHz step size, assuming a 100 step sweep between the start and stop frequency, would allow measuring signals over a 10 GHz frequency range (100 MHz step size X 100 steps) in a single sweep. The output of the mixer 503 is divided into 5 sections and passed through 200 MHz, 20 MHz, 2 MHz, 200 KHz, and 20 KHz Low Pass filters each followed by a detector 504, 505, 506, 507, and 508, and shown as each representing a possible 2Δf bandwidth, all of which outputs are processed in parallel through different multipliers 509, 510, 511, 512, 513, where the signals are multiplied by the IF filter-detector combination of the other half of the circuit, video filters and logarithms (or linear) amplifiers, and the selected multiplier-amplifier output is sent to the Y-axis of the display.

If a signal that occurs within any particular 100 MHz bandwidth segment is recognized by the 200 MHz filter-detector 504, then the 20 MHz bandwidth filter-detector 505 and multiplier 510 output starts to be simultaneously measured in the log amp 514 and the sweep step size is correspondingly reduced to 10 MHz. When the 20 MHz Δf filter starts showing an output, the two LO offsets are reduced to 10 MHz, and the sweep continued. At this point the 2 MHz filter-detector 506 output starts to be measured via multiplier 511 and amplifier 514. And when there is a significant output as set by some amplitude measurement threshold, the step size and Δf is changed to 1 MHz, and the sweep speed is correspondingly reduced. This same sequence of reducing step size and reducing Δf can be carried out until the desired resolution is reached. This is very similar to the situation in a video camera where the aperture is continuously reduced or the zoom continuously increased when an object of interest is noticed. Once the center frequency is passed, the bandwidth

and LO step size can be increased again step by step as Δf frequency thresholds are passed, and the sweep speed correspondingly increased.

This capability of the system, which we call the Adaptive Sweep capability, allows the user of the spectrum analyzer to catch the existence of a signal within microseconds and to set measurement and Resolution bandwidth thresholds based upon the range of frequencies for the signals of interest. This is demonstrated in a time domain picture in FIG. **6**. For example, if the signals of interest are in the 6 to 10 GHz range, then a signal encountered at 2 GHz can be ignored by the simple choice of keeping the Δf and LO step size high, for example at 100 MHz so that no time is spent on adaptive sweeping that particular signal frequency range. When a signal at 7 GHz is encountered as in this example, the system quickly becomes adaptive and pinpoints the frequency of the signal and its sidebands and modulation characteristics. Thus, until the instrument gets close to a signal of interest, **605**, the Δf is kept at 100 MHz, and the LO tunes at speeds and steps in excess of 100 MHz per microsecond. If the unknown signal is at around 6 or 7 GHz, as in this example, the spectrum analyzer can get to the desired frequency in less than 100 microseconds, on the way ignoring the known but undesired signal **604**. When a signal **605** is encountered, a described using FIG. **5**, the Δf, effectively the resolution bandwidth is continuously decreased and the tuning speed is also continuously decreased so the signal can be measured accurately. Once the signal is passed, the speed again increases as Δf is increased and dwell times at each frequency decreased.

Adaptive sweep works well in this system because multiple IF frequency bandwidths, Δf are simultaneously processed and the meaningful aperture or resolution bandwidth can be selected based upon operator input or a preset algorithm. It does not require multiple sweeps as the preselected YIG swept spectrum analyzer would. A typical YIG based spectrum analyzer covering a 10 GHz frequency range requires 400 milliseconds per sweep, and would need 3 to 5 sweeps to center the signal at the desired frequency and zoom in. That is, an accurate signal verification process would take at least 5, usually more than 10 seconds, possibly many times more. The adaptive sweep approach allows this signal capture and analysis to occur in a single sweep. Assuming that the zoom occurs down to 10 KHz bandwidth for a 10 MHz region, the entire process could take less than 20 milliseconds, at least 100 times faster than a traditional spectrum analyzer.

Another capability that the present analyzer architecture results in is the ability for Simultaneous Processing. Simultaneous processing as shown in FIG. **7** affords the user another significant capability, that of being able to analyze a signal at multiple resolution bandwidths simultaneously. The system can have an LO offset that is high, say 100 MHz, but the various Δf filters-detectors **704** through **708** will have an output only when, for any Δf, Fin and Flo are such that the absolute value of (Fin–Flo) is less than Δf. At this point, the appropriate multiplier **709** to **713** will have a non zero output and if this signal is of interest, the sweep can be slowed down by lowering the step size and also if necessary by stepping at the lower value of Δf. The Log Video Amplifiers **714** through **718** simultaneously process any signal and display on multiple windows of the display **719**. Simultaneous Processing is thus a powerful adjunct to Adaptive processing in it that decisions do not necessarily need to be made by reducing Δf in a step wise fashion, but can be made based upon the bandwidth of interest and adjusting sweep step size and speed adaptively. This powerful capability that is made possible by this invention cannot be achieved by traditional methods.

Simultaneous processing is made possible with our architecture because three important parameters can be simultaneously and independently varied. These are the step size of the LO, the resolution bandwidth Δf, the switching speed, and the multiplier and detector chosen. This effectively allows the unit to adaptively sweep and simultaneously process at multiple resolutions and speeds.

To vary the sweep speed as the resolution is reduced, the dwell time at each frequency is controlled. As the resolution bandwidth is reduced, the time that the LOs spend at each frequency is typically increased to allow more accurate measurement of the detected output. With faster digital signal processing capabilities this dwell time can be significantly reduced.

In Radar and Electronic Warfare systems this Adaptive and Simultaneous Processing capability has extensive applicability. In this case the display **719** may not be a display but a signal processor that analyzes the spectrum and possibly generates a countermeasure waveforms.

It should be pointed out that the Δf values as well as the filter bandwidths that are used in the above descriptions are for the purpose of illustration only. They have been chosen so that a clear contrast can be drawn between the traditional preselected approach and the Adaptive and Simultaneous processing approach. In point of fact, for the present system, any set of values that are practical can be used.

To summarize, by using a dual Local Oscillator front end and doing appropriate signal processing post the mixers, we have eliminated the need for preselection. Further, the method allows Adaptive signal processing so one or more signals can be analyzed in a single sweep, or Simultaneous signal processing where multiple spectra of a signal of interest at multiple bandwidth can be simultaneously analyzed or inspected for quick analysis decision making in systems applications with frequency agile inputs.

Another powerful and obvious extension of the patent is that if the incoming signal is divided into multiple paths each covering a narrower range—for example, by building 10 separate receivers that process 2 GHz each to cover a total 20 GHz bandwidth, the signal capture and analysis speed could be reduced to microseconds or even nanoseconds, providing more such a system much more capability than traditional Direct Instantaneous Frequency Measurement receivers used in Electronic Warfare.

Referring to FIG. **8**, if, for example, **803-1** to **803-n** are n Adaptive Analyzers each scanning only 2 GHz, for example, and **804-1** through **804-n** are the corresponding n video filters and logarithmic amplifiers, and **805-1** through **805-n** are the corresponding n displays, and **802** is a Low Noise wideband amplifier and n-way power splitter at the input, and **806** is a controller that takes control commands and simultaneously high speed sweeps with, for example 50 MHz steps and 100 MHz IF in each analyzer arm, then an input signal **801** can be analyzed within 50 MHz accuracy and identified accurately within microseconds. This is much faster than the regular spectrum analyzers and much more accurate than traditional Digital Instantaneous Frequency Measurement devices used in Electronic Warfare.

We claim:

1. A Broadband Receiver usable as an Adaptive Sweep Spectrum or Signal Analyzer (BASA) capable of accurate scanning and measurement of unknown signals at very high speeds and with very high levels of accuracy, consisting of:

    a Signal Splitter at the input to the BASA to split an incoming signal into two parts;

    two Local Oscillators whose output frequencies are symmetrically apart at a selectable frequency separation

from the frequency of the incoming signal being scanned for, the Local Oscillators being tuned together through a frequency range of interest for the measurement;

two Mixers, each of whose input Radio Frequency (RF) signals is one of the two outputs of the Signal Splitter, and each of whose Local Oscillator is one of the two Local Oscillators that are tuned together;

two Low Pass Filters whose bandwidth can be made arbitrarily small to increase accuracy or arbitrarily large to increase speed of scanning and signal identification, respectively filtering the outputs of the two mixers to output any mixer product signals or noise within the low pass filter bandwidth;

two Detectors one each at each low pass filter output that detects and outputs a DC voltage proportional to the input power into each Detector;

an Analog Multiplier that multiplies the two low pass filtered and detected mixer outputs;

a Video Filter and Logarithmic or Linear Amplifier combination whose input attaches to the Analog Multiplier's output and whose output is connected to a display or to a signal processor or analyzer;

wherein when the BASA is used as a Spectrum Analyzer, the X-axis of the Spectrum Analyzer display is a voltage proportional to the incoming frequency being scanned for as a fraction of the total frequency range being scanned for signals, and the Y-axis of the display is the detected and amplified output of the Analog Multiplier;

wherein if there exists a signal, or if there exists noise at the frequency being scanned at the input to the BASA, the detected and amplified output of the Analog Multiplier is proportional to the power of the incoming signal or noise power within the Low Pass Filter bandwidth;

wherein the need for preselection filters at the input so as not to have spurious images is eliminated by a dual Mixer, Local Oscillator, and Low Pass Filter combination, allowing much higher speeds of spectrum scanning and digital phase locked loop accuracy at every frequency

wherein the amplitude accuracy can be controlled via programmable attenuators or some closed loop method that corrects any input splitter imbalance if needed as a function of incoming frequency being scanned for.

2. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **1**, where the Local Oscillators are Frequency Synthesized with a common reference crystal oscillator or signal source.

3. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **1**, where the mixers are harmonic mixers that mix the harmonics of the local oscillator with the frequency being scanned so as to provide a proportional baseband output in the presence of a signal.

4. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **1**, where the low pass filter cutoff frequency can be selected or modified based upon the resolution bandwidth and spectral detail desired.

5. The Broadband Receiver and Adaptive Spectrum Analyzer, BASA of claim **1**, where the speed of tuning of the local oscillator frequencies can be modified based upon the resolution bandwidth desired in any range of scanned frequencies.

6. The Broadband Receiver and Adaptive Spectrum Analyzer, BASA of claim **1**, where the video bandwidth of the video filter is selectable based upon the degree of signal smoothing that is desired.

7. The Broadband Receiver and Adaptive Spectrum Analyzer, BASA of claim **1**, where the controller that controls the scan frequency, scan rate, dwell time at each frequency and other parameters of the system, and the display characteristics is a commercially available or special purpose microcontroller.

8. The Broadband Receiver and Adaptive Spectrum Analyzer, BASA of claim **1**, where the controller that controls the scan frequency, scan rate, dwell time at each frequency and other parameters of the system, and the display characteristics is a PC or other computer based instrument or processor that uses a standard or special purpose instrument bus control.

9. A Broadband Receiver usable as an Adaptive Sweep Spectrum or Signal Analyzer (BASA), capable of accurate scanning and measurement of unknown signals at very high speeds and with very high levels of accuracy, consisting of:

a Signal Splitter at the input to the BASA to split an incoming signal into the BASA into two parts;

two Local Oscillators whose output frequencies are symmetrically apart at a selectable frequency separation from an incoming frequency being scanned for, the Local Oscillators being tuned together through the frequency range of interest for the measurement;

two Mixers, each of whose input Radio Frequency (RF) signals is one of the two outputs of the Signal Splitter, and each of whose Local Oscillators is one of the two Local Oscillators that are tuned together, the Intermediate Frequency (IF) output signal path of each mixer hereafter being referred to as an Arm;

an n-way splitter at the IF output of each mixer, where n is an integer, and can be chosen to be the number of low pass filters needed to set the resolution bandwidths desired for the spectrum analyzer;

selected bandwidth Low Pass Filters at the end of each of the n-way splitter Arms depending upon the various resolution bandwidths desired so that each filter output is a low-pass signal within the selected resolution bandwidth for that Arm;

Detectors one each at each low pass filter output that detect and output a DC voltage proportional to the input power;

an Analog Multiplier at the output of each detector that multiplies the two low pass filtered and detected mixer outputs of one Arm with the corresponding detected output of the other Arm;

an amplifier Video Filter and Logarithmic or Linear Amplifier combination whose input attaches to each analog multiplier output and whose output is connected to a Display Processor or Signal Processor or Signal Analyzer;

wherein when the BASA is used as a Spectrum Analyzer, the X-axis of the Spectrum Analyzer display is a voltage proportional to the incoming frequency being scanned for as a fraction of the total frequency range being scanned for signals, and the Y-axis of the display is the detected and amplified output of the Analog Multiplier;

wherein if there exists a signal, or if there exists noise at the frequency being scanned at the input to the BASA, the detected and amplified output of the Analog Multiplier is proportional to the power of the incoming signal or noise power within the Low Pass Filter bandwidth;

wherein the need for preselection filters at the input so as not to have spurious images is eliminated by the dual Mixer, Local Oscillator, and Low Pass Filter combination, allowing much higher speeds of spectrum scanning and digital phase locked loop accuracy at every frequency;

wherein the amplitude accuracy can be controlled via programmable attenuators or other closed loop means that correct any input splitter imbalance if needed as a function of input frequency;

wherein the Local Oscillator tuning speed and step size are adjusted within any sweep such that the scan speed is high at the parts of the sweep where there is no IF output below some threshold level, or where the signal presence is of no interest to the measurement being made, and is decreased at frequencies where the resolution bandwidth is reduced, so that the sweep speed is adaptive, being low at frequencies where there is a signal of interest and fast where there is none.

10. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9** where the speed of tuning of the local oscillator frequencies can be modified based upon the resolution bandwidth desired in any range of scanned frequencies.

11. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9**, where the video bandwidth of each individual path video filter is selectable based upon the degree of signal smoothing that is desired.

12. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9**, where the controller that controls the step size, scan frequency, local oscillator dwell time at each step and other parameters related to the measurement and the display characteristics, is a commercially available or special purpose microcontroller.

13. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9**, where the controller that controls the step size, scan frequency, local oscillator dwell time at each step and other parameters related to the measurement and the display characteristics, is a PC or other computer based instrument or processor that uses a standard or special purpose instrument bus control.

14. The Broadband Receiver and Adaptive Spectrum Analyzer of claim **9**, where the Local Oscillators are Frequency Synthesized with a common reference crystal oscillator or signal source.

15. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9**, where the mixers are harmonic mixers that mix harmonics of the local oscillator with the frequency being scanned.

16. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **9** wherein the LO separation is kept at the widest possible level, and all the Intermediate Frequency paths are kept active with parallel displays, and where the

sweep step size and sweep speed are adjusted to low values when a signal needs to be recorded or analyzed with a narrow resolution bandwidth, and adjusted for fast response elsewhere, in such a way that multiple signals of interest can be simultaneously viewed and analyzed all within the period of a single sweep thus resulting in an Adaptive Simultaneous Spectrum Analyzer.

17. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16**, where the controller that controls the step size, scan frequency, LO Dwell Time and other parameters related to the measurement and the display characteristics, is a commercially available or special purpose microcontroller.

18. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16**, where the controller that controls the scan frequency, rate and other parameters of the system, and the display characteristics is a PC or other computer based instrument or processor that uses a standard or special purpose instrument bus control.

19. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16**, where the Local Oscillators are Frequency Synthesized with a common reference crystal oscillator or signal source.

20. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16**, where the mixers are harmonic mixers that mix harmonics of the local oscillator with the frequency being scanned.

21. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16** where the speed of tuning of the local oscillator frequencies is changed based upon the resolution bandwidth desired in any range of scanned frequencies.

22. The Broadband Receiver and Adaptive Spectrum Analyzer BASA of claim **16**, where the video bandwidth of each individual path video filter is selectable based upon the degree of signal smoothing that is desired.

23. The Broadband Receiver and Adaptive Spectrum Analyzer BASA capable of Simultaneous processing of claims **9**, **16**, **17**, **18**, **19**, **20**, **21**, or **22** consisting of a selectable number of receivers, n, covering different bandwidths such that the incoming signal is split n ways and processed simultaneously so that signals covering wide frequency ranges can be broken into a number of smaller frequency ranges, and can be scanned and analyzed at n times the speed of a single broadband LO sweep so as to provide almost Instantaneous Frequency Measurement and signal analysis capabilities.

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